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A Model Which Predicts Pacific Herring (*Clupea harengus pallasi*) Egg Deposition on Giant Kelp (*Macrocystis* sp.) Plants from Underwater Observations

C. W. Haegele and J. F. Schweigert

Department of Fisheries and Oceans
Biological Sciences Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

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A MODEL WHICH PREDICTS PACIFIC HERRING (*Clupea harengus pallasi*) EGG DEPOSITION ON GIANT KELP (*Macrocystis* sp.) PLANTS FROM UNDERWATER OBSERVATIONS

by

C. W. Haegele and J. F. Schweigert

Department of Fisheries and Oceans
Biological Sciences Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

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ABSTRACT

Haegele, C. W. and J. F. Schweigert. 1990. A model which predicts Pacific herring (*Clupea harengus pallasi*) egg deposition on giant kelp (*Macrocystis* sp.) plants from underwater observations. Can. MS Rep. Fish. Aquat. Sci. 2056: 17 p.

Pacific herring (*Clupea harengus pallasi*) spawn is routinely surveyed to estimate escapement. When spawn is deposited on the giant kelp (*Macrocystis* sp.), SCUBA divers make observations on the number of egg layers, the height of the kelp plants, and the number of fronds per kelp plant. A multiple regression model that predicts eggs per plant from these observations was developed from data collected for 167 plants between 1981-1987. The model accounted for 78% of the total variation in the $\log_e$ transformed eggs per plant and was a highly significant fit to the observed data ($P < 0.0001$). Total herring egg deposition on *Macrocystis* sp. is estimated using this model in conjunction with estimates of plant density and spawning bed area.

RÉSUMÉ

Haegele, C. W. and J. F. Schweigert. 1990. A model which predicts Pacific herring (*Clupea harengus pallasi*) egg deposition on giant kelp (*Macrocystis* sp.) plants from underwater observations. Can. MS Rep. Fish. Aquat. Sci. 2056: 17 p.

On effectue régulièrement des relevés de la fraye de harengs du Pacifique (*Clupea harengus pallasi*) pour estimer les échappées. Quand les oeufs sont déposés sur les algues géantes (de genre *Macrocystis*), des plongeurs déterminent le nombre de géniteurs, la hauteur des algues et le nombre de frondes par plante. Les données relatives à 167 plantes recueillies de 1981 à 1987 ont permis d'élaborer un modèle de régression multiple qui prévoit le nombre d'oeufs par plante à partir des observations. Le modèle a prévu avec un taux d'efficacité de 78% la variation totale du logarithme naturel du nombre d'oeufs par plante, résultat qui présente une très grande concordance avec la variation réalle ($P < 0,0001$). On utilise ce modèle, ainsi que des estimations de la densité d'algues et de la superficie des frayères, pour estimer le nombre total d'oeufs déposés sur *Macrocystis*.

INTRODUCTION

SCUBA surveys began replacing traditional surface based surveys of Pacific herring (*Clupea harengus pallasi*) spawn in British Columbia in 1988. SCUBA surveys are designed to estimate spawning escapement for stock assessment to within 25% of the true spawn deposition (Schweigert et al. 1985).

For eggs that are deposited on marine vegetation, a non-linear model is used to predict egg density from diver observations of the type of vegetative substrate, the number of egg layers on the vegetation, and the proportion of the sample quadrat covered by vegetation (Schweigert and Fournier 1982). However, this model does not predict egg numbers for spawn that is deposited on the giant kelp, *Macrocystis* sp., which occurs along the more exposed shorelines. In the Queen Charlotte Islands, *Macrocystis* sp. has been estimated to accommodate 25% of the total spawn (Haegele and Schweigert 1987). A method that estimates eggs on *Macrocystis* sp. was developed by Haegele and Schweigert (1985) and was used in subsequent spawn surveys (eg. Haegele and Schweigert 1987). This method requires the harvesting of individual plants for either (1) egg counts (best estimate), or (2) the weight of plant material and attached eggs (good estimate), or (3) the number of blades per plant (reasonable estimate).

The objective of this paper is to present a multiple regression model which can be used to predict eggs on *Macrocystis* sp. from *in situ* diver observations of the average number of egg layers, plant height, and number of fronds per plant. It does not require harvesting plants.

METHODS

Herring spawn on *Macrocystis* sp. plants was sampled in the Queen Charlotte Islands (38 plants in 1981 and 74 plants in 1987), on the North Coast (15 plants in 1986), on the Central Coast (5 plants in 1986), and on the west coast of Vancouver Island (11 plants in 1985 and 24 plants in 1986) (Fig. 1). Divers harvested whole *Macrocystis* sp. plants and brought them to the surface, holdfast first, after untangling the fronds from those of adjacent plants. Plants were cut into 1 m sections in the workboat, bagged separately, and transported to a shipboard laboratory. Each section was weighed, mature fronds[1] were counted, and egg layers were estimated. One blade and associated stipe from each section was weighed and preserved in Gilson's fluid. The preserved samples were later immersed in alcoholic (25% by volume) 1N KOH at 40° C for approximately 1 hr to liberate the eggs. (This solution dissolves

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[1]Fronds were considered mature when they were > 1 m long. Fronds < 1 m long generally consisted of meristematic material to which few eggs adhered.

the glue by which herring eggs are attached.) Eggs were then stored in 10% formalin for at least 1 wk for hardening. The preservative was vacuum extracted, the eggs weighed, and 2 aliquots of approximately 200-400 eggs removed, weighed and the eggs counted. Total egg numbers for each 1 m section were then calculated and egg numbers per plant estimated from the sum of sections. Similarly, from the data collected for the 1 m sections, mean number of egg layers per plant, total plant height (the length of the longest frond), and total number of fronds per plant were estimated (Table 1).

Scatter plots of the number of eggs per plant with the other variables (egg layers, plant height, and fronds per plant) were generated for all 167 data points. Multiple linear regression analysis was used to develop predictive models for the number of eggs per plant using the three predictor variables described above. For the best model (highest r^2), residual plots were examined for outliers and adequacy of model fit. We compared predicted with observed egg numbers for each sampling area.

RESULTS

A variety of regression models were fitted to the egg layer, plant height, and frond number data incorporating transformations (Table 2). Logarithmic transformation ($\log_e$) of dependent and independent variables indicated that the transformation had adequately linearized the data and no obvious outliers were present (Fig. 2a-c). The multiple regression model that best described the observed egg numbers was:

$$E = 0.073 \cdot L^{0.673} \cdot H^{0.932} \cdot F^{0.703},$$

where

E = eggs per *Macrocystis* sp. plant in millions,
L = average egg layers on the plant,
H = plant height, and
F = number of mature fronds.

This model accounted for 78% of the total variation in the log transformed eggs per plant and was a highly significant fit to the observed data ($P < 0.0001$). The plots of the residuals versus the predicted eggs per plant and against the dependent variables indicated no problems with model fit and no obvious outliers (Fig. 3a-d). Examination of leverage and influence statistics indicated that 4 observations were outliers. These were examined in detail but did not appear to be erroneous although they were unusual.

The plots of the observed versus predicted eggs per plant indicate some anomalies (Fig. 4a-d). The predicted eggs per plant for the Queen Charlotte Islands in 1981 appear to be too low for the heavier egg depositions, i.e. those exceeding 10 million eggs per plant. Predictions of eggs per plant for the other areas do not differ systematically from the

observed eggs per plant, although the variability in observed versus predicted eggs per plant increases with eggs per plant. Only 5 plants were collected from the Central Coast in 1986 and these data are not plotted here. The significance of the apparent differences between observed and predicted eggs per plant were tested statistically using a paired t-test (Table 3). The results indicate that the model predictions differ significantly from the observed egg numbers in the Queen Charlotte Islands in 1981 and on the west coast of Vancouver Island in 1986. However, when the results for these areas are combined over years, there are no significant differences between observed eggs per plant and model predictions. This suggests that, although there may be difficulties predicting eggs for *Macrocystis* sp. plants in certain areas in some years at particular egg densities, overall, the model should provide a reasonable means for estimating eggs deposited on *Macrocystis* sp. plants.

DISCUSSION

Estimating herring egg deposition on *Macrocystis* sp. for stock assessment and management of the British Columbia roe fishery remains an important yet difficult problem. *Macrocystis* sp. occurs primarily on outer coast herring spawning grounds and not on those in Johnstone, Georgia, or Juan de Fuca straits. Generally, it is not the prime herring spawning substrate although on some spawning grounds in the southeastern Queen Charlotte Islands and northern Porcher Island, it is the main and sometimes the only spawning substrate. Prior to 1986, *Macrocystis* sp. was treated similarly to other algal types in the usual surface surveys of herring spawning grounds that estimated length, width, and egg density (Schweigert and Stocker 1988, Hay and Kronlund 1988). Unfortunately, the third dimension (plant height) of this algae, which at times exceeds 15 m, makes attempts to accurately assess egg deposition on *Macrocystis* sp. from the surface extremely difficult if not impossible. The methodology we devised to estimate egg deposition using SCUBA is at best approximate, but should provide at least the correct order of magnitude estimate of total egg deposition on *Macrocystis* sp. (Haegele and Schweigert 1985).

The surveys for the development of this SCUBA method and subsequent synoptic spawn surveys provided the data base for this study. As detailed earlier, we obtained accurate information on the size of individual plants and egg deposition thereon. Unfortunately, for the visual spawn surveys done routinely by fisheries officers using SCUBA throughout the British Columbia coast (eg. Haist and Schweigert 1989), it is only possible to obtain estimates of the average egg layers and plant height for all the *Macrocystis* sp. plants in a spawning bed. In addition, fronds are counted for each plant along individual transects, permitting us to estimate the average number of fronds per plant. Subsequently, these average values are used in the predictive equation developed here to estimate average eggs per plant. This, combined with plant density, is used to estimate egg deposition on *Macrocystis* sp. for each spawning ground.

The results presented earlier indicate that the predictive model developed from the 167 Macrocystis plants collected during research and synoptic surveys from 1981 through 1987 provides reasonably accurate estimates of egg numbers for these areas. In some instances, where some plants were unusually large (Queen Charlotte Islands, 1981) or small (west coast of Vancouver Island, 1986), the estimates were not as accurate. However, as a general model we expect that our estimates should be quite accurate. Unfortunately, there seems to be no real possibility for testing the estimates provided by the synoptic survey short of harvesting a number of *Macrocystis* sp. beds and comparing the estimates from egg counts to those from predictions based on the average values estimated over all plants in the beds. In fact, this should probably be attempted in a few instances where small beds of plants that could be readily harvested are available.

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Table 1. Observations and measurements for herring spawn on *Macrocystis* sp. plants sampled between 1981-1987.

Area	Year	Height (m)	Fronds/plant	Egg layers	Eggs/plant ($\cdot 10^{-6}$)
QCI	1981	1	8	2.00	0.61
QCI	1981	2	1	0.19	0.19
QCI	1981	2	1	2.31	0.26
QCI	1981	2	2	2.22	0.16
QCI	1981	2	2	2.59	0.27
QCI	1981	3	1	2.42	0.20
QCI	1981	3	2	1.16	0.74
QCI	1981	3	4	1.84	0.89
QCI	1981	3	4	3.81	1.06
QCI	1981	3	5	3.50	2.45
QCI	1981	3	6	2.58	2.74
QCI	1981	3	10	3.85	1.81
QCI	1981	4	2	3.19	4.41
QCI	1981	4	5	4.81	4.96
QCI	1981	4	7	1.29	1.98
QCI	1981	4	8	2.66	3.51
QCI	1981	5	5	3.66	1.93
QCI	1981	5	9	5.24	12.86
QCI	1981	5	15	5.28	21.30
QCI	1981	6	4	2.74	1.63
QCI	1981	6	6	2.56	1.78
QCI	1981	6	15	5.05	15.05
QCI	1981	7	6	1.98	3.53
QCI	1981	7	7	1.90	7.31
QCI	1981	7	12	4.41	9.45
QCI	1981	7	13	2.48	4.24
QCI	1981	7	15	3.59	14.00
QCI	1981	8	4	3.80	2.97
QCI	1981	8	6	1.99	4.38
QCI	1981	8	7	1.52	1.47
QCI	1981	8	8	3.89	10.05
QCI	1981	8	10	2.46	3.16
QCI	1981	8	11	1.41	2.29
QCI	1981	8	18	2.95	5.04
QCI	1981	9	14	1.88	4.17
QCI	1981	10	19	2.73	6.09
QCI	1981	11	15	3.75	49.55
QCI	1981	12	51	5.43	39.45
QCI	1987	2	4	5.69	0.96
QCI	1987	2	6	0.74	0.28
QCI	1987	2	6	0.75	0.37
QCI	1987	2	6	0.88	0.39
QCI	1987	3	2	2.38	0.21

Table 1 (cont'd)

Area	Year	Height (m)	Fronds/plant	Egg layers	Eggs/plant ($\cdot 10^{-6}$)
QCI	1987	3	4	0.51	0.40
QCI	1987	3	4	1.35	1.13
QCI	1987	3	4	10.00	2.35
QCI	1987	3	6	1.34	1.74
QCI	1987	3	7	0.27	0.32
QCI	1987	3	8	1.26	0.90
QCI	1987	3	8	1.57	5.65
QCI	1987	3	9	3.38	4.03
QCI	1987	3	10	3.22	0.78
QCI	1987	3	17	3.16	2.09
QCI	1987	4	6	0.79	0.29
QCI	1987	4	6	11.19	2.14
QCI	1987	4	7	2.20	2.87
QCI	1987	4	10	3.39	3.14
QCI	1987	4	11	0.85	0.61
QCI	1987	4	12	1.54	1.54
QCI	1987	4	17	0.35	0.77
QCI	1987	4	22	2.39	2.55
QCI	1987	5	4	17.73	3.44
QCI	1987	5	5	2.04	5.49
QCI	1987	5	10	0.57	1.62
QCI	1987	5	12	0.53	0.33
QCI	1987	5	12	1.90	6.43
QCI	1987	5	18	1.46	1.02
QCI	1987	5	19	1.50	1.70
QCI	1987	5	27	0.30	1.29
QCI	1987	6	6	4.65	2.90
QCI	1987	6	7	4.69	6.55
QCI	1987	6	13	2.42	1.39
QCI	1987	6	14	2.70	11.02
QCI	1987	6	21	10.64	14.81
QCI	1987	6	22	1.27	5.83
QCI	1987	6	30	0.54	0.65
QCI	1987	7	4	2.92	7.46
QCI	1987	7	4	5.20	5.98
QCI	1987	7	8	0.91	6.20
QCI	1987	7	10	1.27	1.96
QCI	1987	7	13	4.35	2.91
QCI	1987	7	16	2.51	6.70
QCI	1987	7	18	0.33	2.43
QCI	1987	7	20	1.30	2.02
QCI	1987	7	21	2.38	7.95
QCI	1987	8	5	4.89	8.06
QCI	1987	8	7	0.36	1.60

Table 1 (cont'd)

Area	Year	Height (m)	Fronds/plant	Egg layers	Eggs/plant ($\cdot 10^{-6}$)
QCI	1987	8	16	2.73	11.29
QCI	1987	9	7	3.28	1.40
QCI	1987	9	15	0.45	3.92
QCI	1987	9	21	3.10	8.70
QCI	1987	9	23	5.40	23.59
QCI	1987	9	25	0.32	5.22
QCI	1987	9	32	7.47	56.91
QCI	1987	10	6	2.19	0.52
QCI	1987	10	10	5.11	15.12
QCI	1987	10	13	2.06	12.99
QCI	1987	10	14	0.30	8.15
QCI	1987	10	22	1.84	6.45
QCI	1987	10	23	1.28	5.59
QCI	1987	10	24	1.38	6.35
QCI	1987	11	33	1.23	17.93
QCI	1987	11	74	0.20	6.85
QCI	1987	12	13	1.20	7.12
QCI	1987	12	15	3.06	43.12
QCI	1987	12	38	9.35	75.75
QCI	1987	13	16	2.59	13.11
QCI	1987	14	15	2.10	8.34
QCI	1987	14	21	4.37	35.49
QCI	1987	14	28	5.67	36.28
QCI	1987	14	48	4.55	29.39
QCI	1987	15	17	6.09	8.83
NC	1986	5	9	0.14	0.27
NC	1986	6	7	0.90	0.94
NC	1986	6	12	1.70	3.47
NC	1986	7	8	0.12	0.22
NC	1986	7	8	0.30	1.31
NC	1986	8	9	1.60	1.96
NC	1986	8	11	0.90	2.64
NC	1986	9	6	4.50	3.20
NC	1986	10	16	1.10	3.45
NC	1986	11	12	0.90	4.94
NC	1986	11	18	0.70	7.30
NC	1986	12	12	1.25	5.12
NC	1986	15	21	0.84	4.37
NC	1986	16	11	1.00	8.35
NC	1986	19	5	0.44	0.64
CC	1986	3	1	0.53	0.27
CC	1986	4	17	1.03	0.94
CC	1986	5	1	1.79	0.10
CC	1986	6	7	0.21	0.53

Table 1 (cont'd)

Area	Year	Height (m)	Fronds/plant	Egg layers	Eggs/plant ($\cdot 10^{-6}$)
CC	1986	6	8	0.56	0.79
WCVI	1985	1	1	0.70	0.45
WCVI	1985	1	2	1.70	0.43
WCVI	1985	2	2	5.76	0.75
WCVI	1985	3	4	1.10	0.15
WCVI	1985	3	4	3.11	0.70
WCVI	1985	3	5	1.13	1.06
WCVI	1985	3	5	1.33	1.48
WCVI	1985	4	4	0.12	0.13
WCVI	1985	5	4	0.34	1.61
WCVI	1985	5	6	0.62	1.09
WCVI	1985	9	9	3.06	1.02
WCVI	1986	1	2	3.00	0.06
WCVI	1986	2	1	0.10	0.02
WCVI	1986	2	1	0.50	0.05
WCVI	1986	2	1	2.50	1.23
WCVI	1986	2	2	0.10	0.04
WCVI	1986	2	2	2.70	0.67
WCVI	1986	2	3	2.60	0.44
WCVI	1986	2	4	3.00	0.57
WCVI	1986	3	1	5.04	0.74
WCVI	1986	3	2	0.40	0.32
WCVI	1986	3	2	0.90	0.26
WCVI	1986	3	2	1.20	0.14
WCVI	1986	3	3	0.04	0.09
WCVI	1986	3	3	1.32	0.26
WCVI	1986	3	4	1.48	0.40
WCVI	1986	3	4	1.70	0.61
WCVI	1986	4	3	1.30	0.40
WCVI	1986	4	3	2.40	0.83
WCVI	1986	4	5	1.00	0.29
WCVI	1986	4	5	2.65	1.00
WCVI	1986	4	6	3.10	2.40
WCVI	1986	5	2	0.90	0.15
WCVI	1986	7	15	0.92	0.62
WCVI	1986	7	20	1.20	3.64

Table 2. Herring eggs (in millions) per *Macrocystis* sp. plant (E) prediction equations based on average egg layers (L), plant height (H) and number of mature fronds per plant (F). (P for all regressions was <0.001).

Model	r^2	d.f.	F-value
$E = 0.910 \cdot 1.338L$	0.185	1, 165	37.553
$E = 0.313 \cdot 1.342H$	0.434	1, 165	126.593
$E = 0.681 \cdot 1.097F$	0.347	1, 165	87.651
$E = 1.271 \cdot L^{0.805}$	0.279	1, 165	63.835
$E = 0.103 \cdot H^{1.776}$	0.486	1, 165	155.833
$E = 0.161 \cdot F^{1.224}$	0.507	1, 165	169.652
$E = 0.183 \cdot 1.292L \cdot 1.323H$	0.576	2, 164	111.324
$E = 0.256 \cdot L^{0.708} \cdot 1.313H$	0.647	2, 164	150.462
$E = 0.065 \cdot 1.283L \cdot H^{1.687}$	0.619	2, 164	133.453
$E = 0.092 \cdot L^{0.697} \cdot H^{1.648}$	0.692	2, 164	184.150
$E = 0.387 \cdot 1.293L \cdot 1.092F$	0.490	2, 164	78.670
$E = 0.501 \cdot L^{0.759} \cdot 1.093F$	0.594	2, 164	119.951
$E = 0.098 \cdot 1.285L \cdot F^{1.285}$	0.643	2, 164	147.813
$E = 0.139 \cdot L^{0.691} \cdot F^{1.135}$	0.709	2, 164	200.255
$E = 0.297 \cdot 1.239H \cdot 1.649F$	0.502	2, 164	82.739
$E = 0.124 \cdot H^{1.363} \cdot 1.047F$	0.542	2, 164	96.987
$E = 0.134 \cdot 1.168H \cdot F^{0.846}$	0.579	2, 164	112.695
$E = 0.080 \cdot H^{1.000} \cdot F^{0.758}$	0.587	2, 164	116.685
$E = 0.177 \cdot 1.280L \cdot 1.229H \cdot 1.048F$	0.634	3, 163	94.059
$E = 0.243 \cdot L^{0.711} \cdot 1.210H \cdot 1.052F$	0.717	3, 163	137.635
$E = 0.111 \cdot L^{0.700} \cdot H^{1.226} \cdot 1.047F$	0.750	3, 163	163.190
$E = 0.118 \cdot L^{0.675} \cdot 0.144H \cdot F^{0.785}$	0.772	3, 163	183.544
$E = 0.078 \cdot 1.274L \cdot H^{1.305} \cdot 1.043F$	0.668	3, 163	109.247
$E = 0.052 \cdot 1.274L \cdot H^{0.939} \cdot F^{0.732}$	0.714	3, 163	135.623
$E = 0.083 \cdot 1.278L \cdot 1.158H \cdot F^{0.809}$	0.708	3, 163	131.801
$E = 0.073 \cdot L^{0.673} \cdot H^{0.932} \cdot F^{0.703}$	0.779	3, 163	191.653

Table 3. Paired t-tests comparing observed and predicted eggs per *Macrocystis* sp. plant in areas surveyed between 1981-1987.

Survey Area	Survey Year	Number of Plants	Mean eggs per plant[a] Observed	Mean eggs per plant[a] Predicted	Student's t-value	Probability level
QCI	1981	38	1.006	0.784	2.150	0.038
QCI	1987	74	1.219	1.199	0.239	0.812
QCI	All	112	1.147	1.057	1.333	0.185
NC	1986	15	0.735	0.910	-1.362	0.195
CC	1986	5	-0.910	-0.512	-1.037	0.858
WCVI	1985	11	-0.472	-0.644	0.515	0.618
WCVI	1986	24	-1.121	-0.816	-2.158	0.042
WCVI	All	35	-0.917	-0.762	-1.070	0.292

[a]Both observed and predicted mean eggs per plant refer to the natural logarithm of eggs in millions.

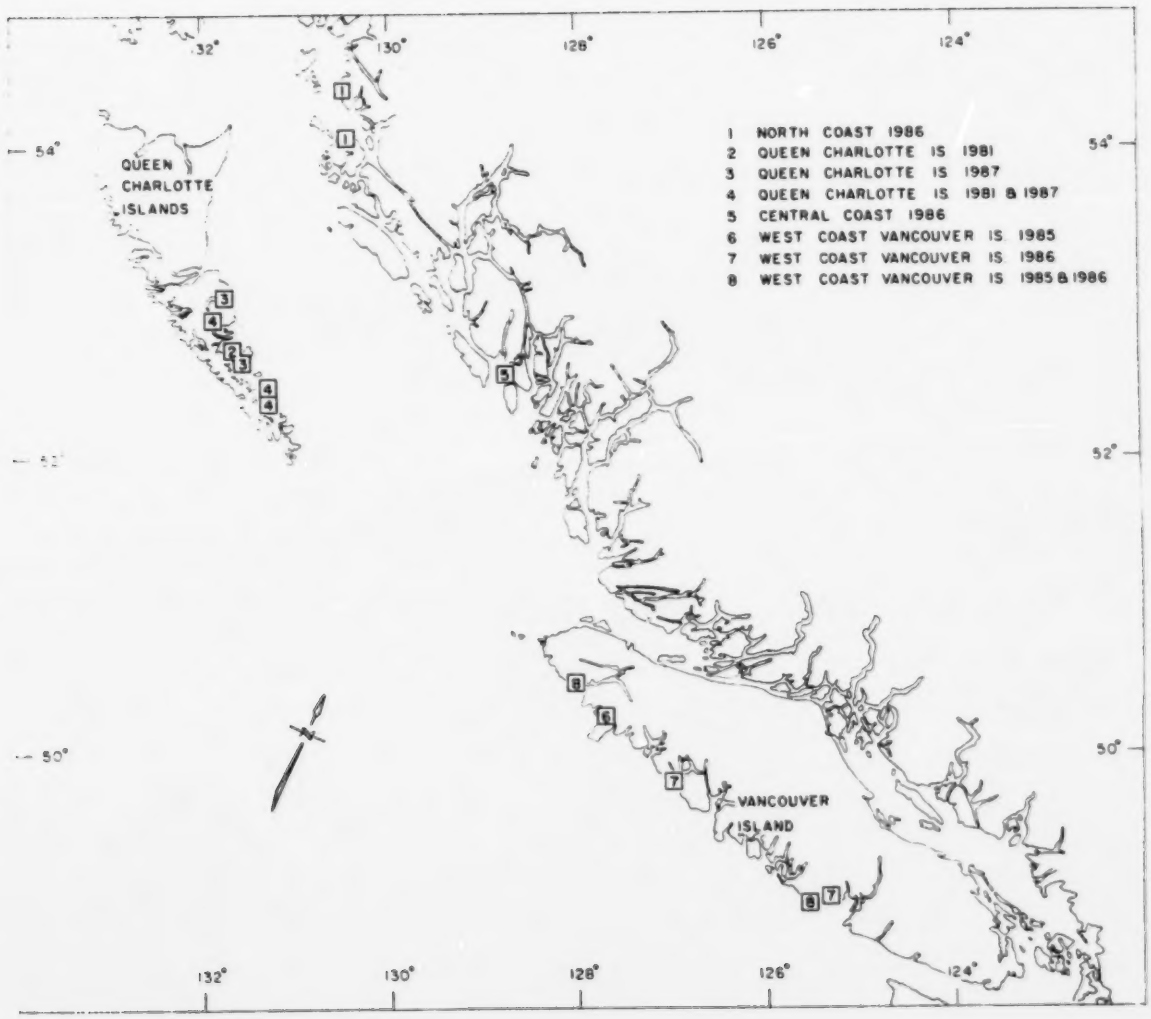

Fig. 1. Sites at which *Nacrocystis* sp. plants with herring spawn were collected between 1981-1987.

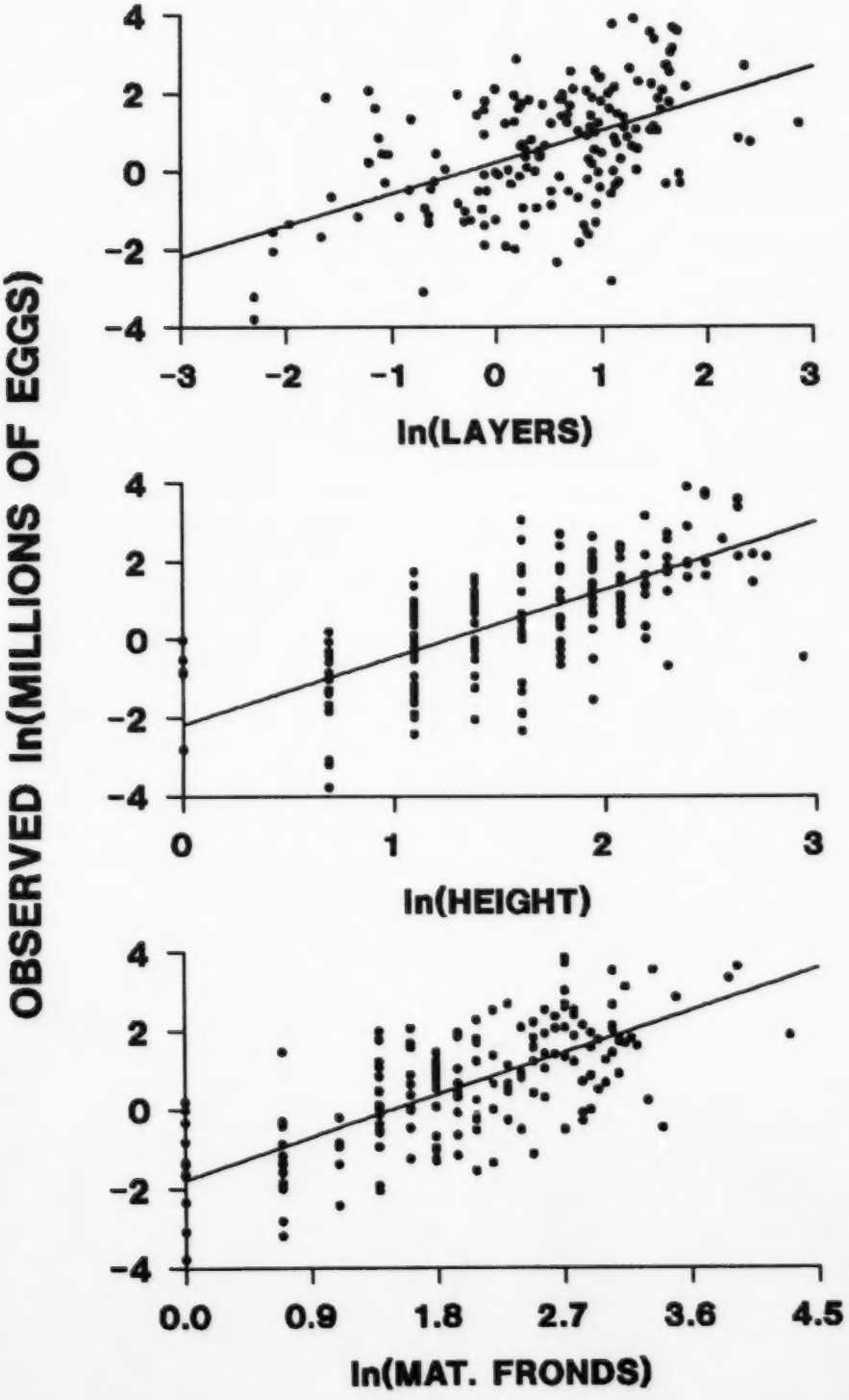

Fig. 2. Bivariate plots of the $\log_e$ transformed eggs per plant in millions and the predictor variables a) average egg layers per plant, b) plant height in meters, and c) mature fronds per plant.

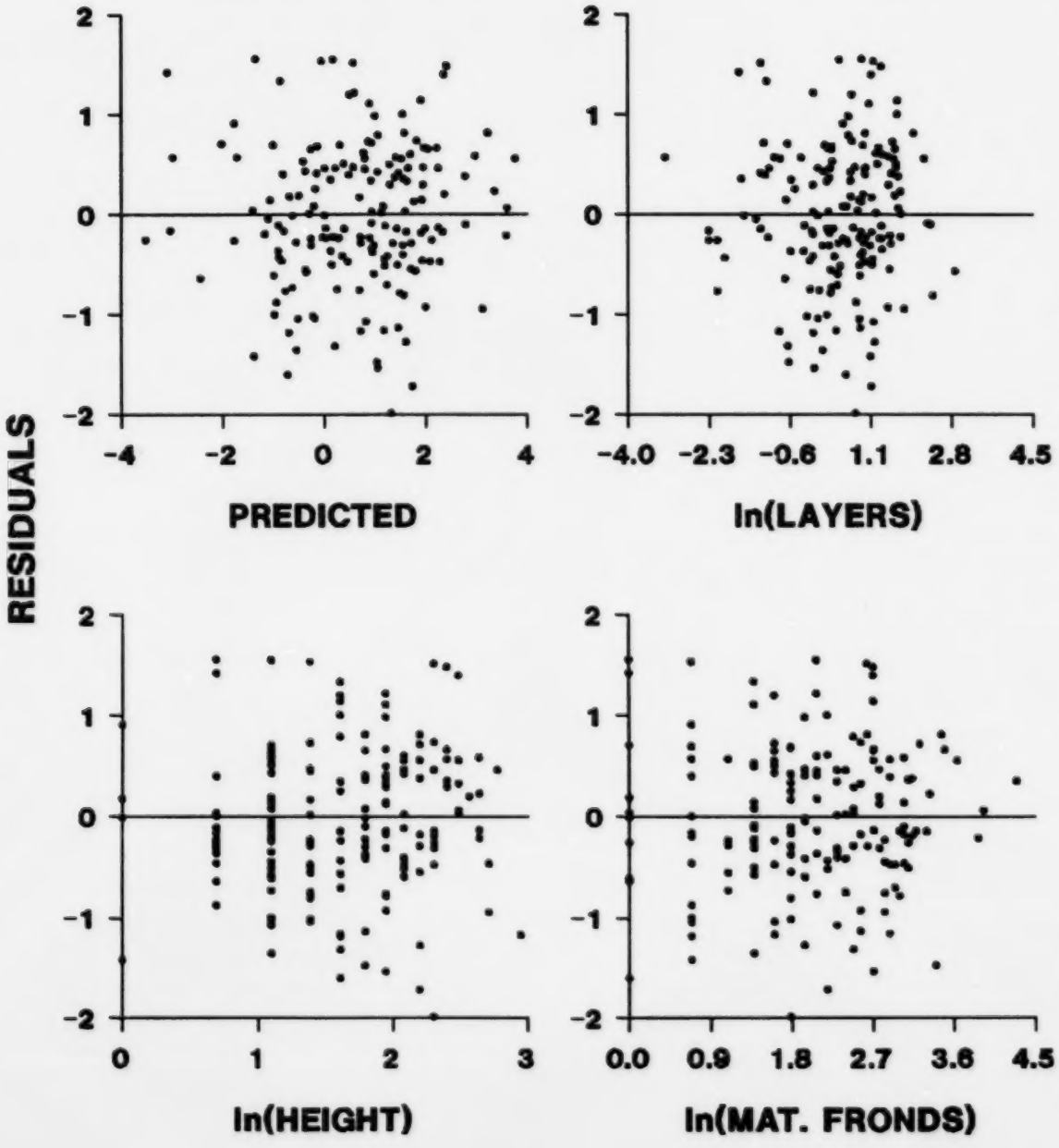

Fig. 3. Bivariate plots of the residuals from the *Macrocystis* sp. egg prediction model and the a) predicted number of eggs, b) average egg layers per plant, c) plant length in meters, and d) number of fronds per plant.

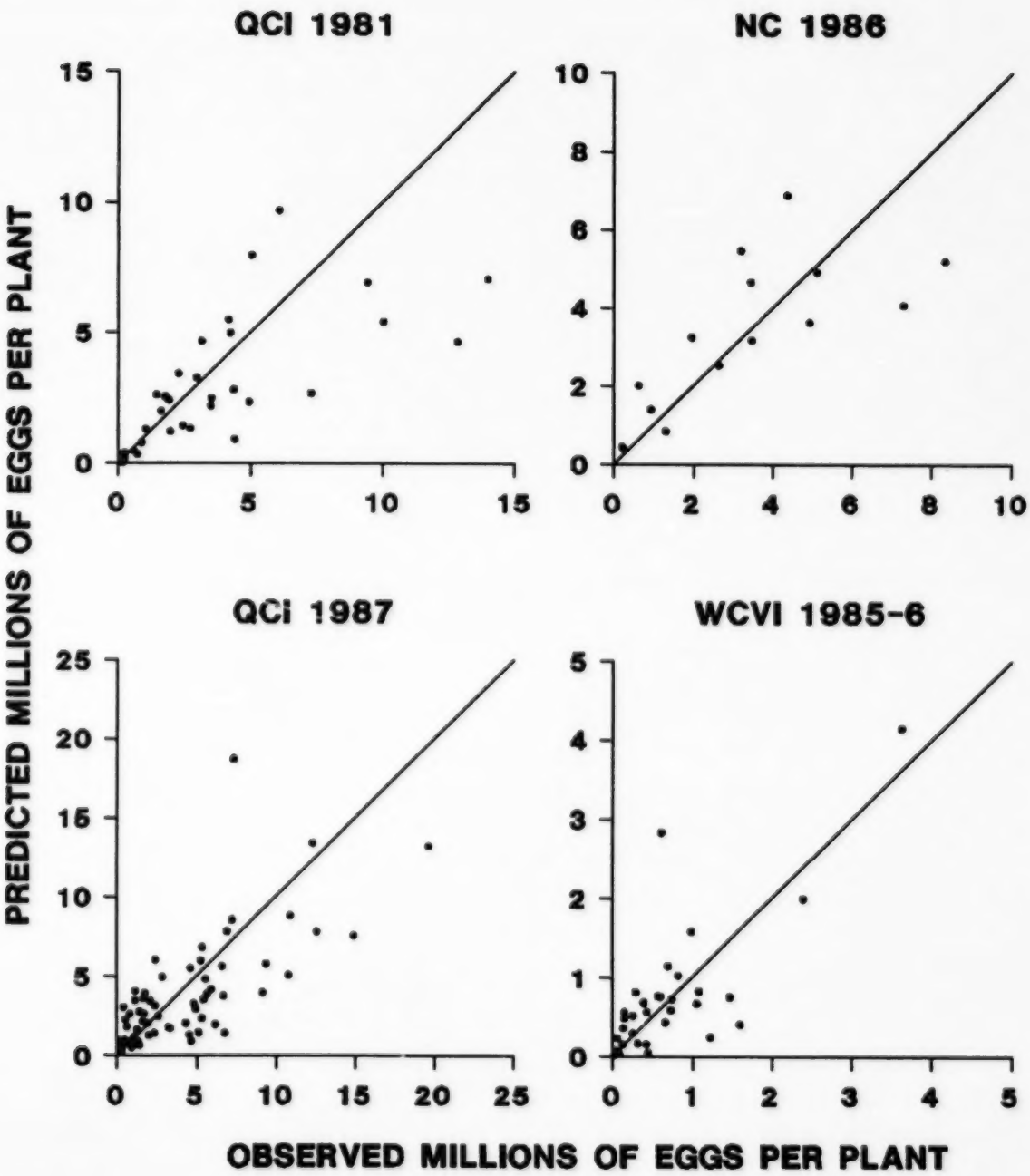

Fig. 4. Scatter plot of the predicted millions of eggs per plant versus the observed millions of eggs per plant for the Queen Charlotte Islands (QCI) in 1981 and 1987, the North Coast (NC) in 1986, and for the west coast of Vancouver Island (WCVI) both in 1985 and 1986. Plants with > 25 million eggs (7 plants) were not plotted to allow reasonable resolution of the data.